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SOME PHYSICAL AND FRICTIONAL PROPERTIES OF DIKANUT (*IRVINGIA WOMBOLU*) AS A FUNCTION OF MOISTURE CONTENT.

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A B S T R A C T: *Some physical and frictional properties of Dikanut (Irvingia wombolu) were evaluated as a function of moisture content varying from 7.02% to 15.04% (dry basis). Regression models were equally developed to these effects. All properties studied were found to have a polynomial response to moisture content increase within the moisture content range studied (7.02% to 15.04% dry basis). The kernel dimensions increased from 44.00 to 47.73mm, 33.50 to 34.89mm, 20.60 to 21.79mm and 32.20 to 33.73mm for major, intermediate, minor and equivalent diameters respectively as moisture content increased. The kernel volume and surface area increased from 120.01mm^3 to 158.56mm^3 and 102.04mm^2 to 131.64mm^2. Bulk density and true density increased from 3.64g/cm^3 to 4.33g/cm^3, and 10.31g/cm^3 to 12.26g/cm^3 respectively with increase in the moisture content range tested. Aspect ratio and sphericity and porosity increased from 0.74 to 0.79; 0.70 to 0.72; 0.41 to 0.60 respectively within the moisture content range studied. Angle of repose increased from 20.10˚to 37.20˚while static coefficient of friction increased from 0.60 to 0.92 (plywood), 0.50 to 0.82 (mild steel), 0.37 to 0.70 (aluminum), 0.30 to 0.64 (plastic) as moisture content increased from 7.02 to 15.04% (dry basis) with plywood giving the highest range of values. The relevant data obtained for this variety would be useful for design and development of machines and equipment for processing and handling operations.*

KEYWORD: Physical Properties, Dikanut, Moisture Content, Postharvest, Processing

INTRODUCTION

Dikanut is an extract of wild mango (*Irvingia* Spp.) which is grown for its fruits and kernels popularly known as *ugiri* and *ogbono* (Igbo) respectively in Nigeria. The edible fruit (*Irvingia gabonensis*) is eaten fresh or used to make juice and the kernel when ground is used to make *ogbono* soup but the no-edible (*Irvingia wombolu*) is solely grown for the production of *ogbono* from its kernels. The powder of the kernel is also used as ingredient in other sauces like tomatoes and groundnut for a sticky effect and taste (Ehiem and Simonyan, 2012). Extracts of *ogbono* seed can be used to reduce obesity, cholesterol and chances of developing degenerative diseases such as diabetes, cancer, high blood pressure, kidney failure, heart attack and stroke (Leakey et al., 2005; Ngodi et al., 2005). Processing Dikanut involves four stages: separating the mesocarp from hard endocarp (done manually using knife to peel off the mesocarp or allow it to rot); cracking the stony endocarp with hammer or stone to remove the kernel (splitting fresh fruit into two with sharp knife can also be used to extract the kernel); drying the extracted kernel to storable moisture content and finally, grinding the kernel to powder. The kernel composed about 62.8% lipids, 19.7% carbohydrates, 8.9% protein, 5.3% dietary fibre and 3.2% ash (Ejiofor, 1994). Carbonized Dikanut shell which is an abundant agricultural waste can be

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relevant as an alternative to synthetic carbon black for reinforcing both natural and synthetic rubber, thereby converting low value underutilized resources to high value product (Adeosun, 2002). The conversion of Dikanut shell to polymeric filler has several benefits. First, it provides a cheap, renewable, abundant and biodegradable source of reinforcement to polymeric systems. Second, it offers an effective, innovative and alternative solution to indiscriminate dumping of agro-wastes, thereby preventing them from polluting the environment either through incineration or filling up landfills and waterways (Onyeagoro *et al.*, 2014).

Fig. 1.1a
Wild mango fruit and splinted Dikanut kernel (*Irvingia wombolu*)

Fig. 1.1b
De-husked Dikanut Kernel (*ogbono)*

The knowledge of physical and frictional (flow) properties of agricultural products as a function of its moisture content is important in providing essential engineering data required for design and development of machines, structures and equipment for handling, dehusking, processing, transporting and storage of agricultural product. Shape and size are relevant in designing equipment for grading, sorting, cleaning, dehulling and packaging. Density with specific gravity are used for calculating thermal diffusivity in heat transfer, terminal velocity, mass, bulk density and porosity are employed in storage, transportation and separation system (Oh *et al*., 2001; Urena *et al*., 2002). Therefore, the knowledge of the physical and frictional properties of food and agricultural product as a function of moisture content is vital for decision making and design consideration during the design of handling and processing machines and systems as well as the development of new consumer products.

Due to the hectic nature of the processing Dikanut (*ogbono*), mechanization of this process has been of high interest in recent times so as to increase the efficiency of this production process. But the achievement of optimum mechanization of this process cannot be made with total success without proper study of the various physical and frictional properties of the Dikanut as a function of moisture content which is the essence of this research.

Objectives

- To determine the effect of moisture content on some physical and frictional properties of Dikanut (*Irvingia wolumbolu)* necessary for the design of various separating, handling, storage, processing and drying machines and systems.
- To develop regression models of these effects.

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Scope of Work

This research covered the analysis of some physical properties (necessary for the design of selective kernel separators, seed handling machine parts, machines and equipment) and frictional properties (necessary for defining the flowabilty of the kernels thereby aiding in proper design decision making with regards to seed conveyance) of Dikanut (*Irvingia wolombolu*) at a moisture content range of 7.02% to 15.04% (dry basis)

METHODOLOGY

Dikanuts (*Irvingia wombolu*) used for this study were purchased from rural farmers in Amuzuoro Ibeku village – Umuahia, Abia State which is located in the rain forest vegetation zone of South eastern Nigeria and lies between 04° 401 and 06° 141 N and 07° 101 and 08° E, due to unavailability of unprocessed Dika-nut kernels in urban markets. About 27kg of Dikanut kernels were purchased and after sorting out of whole nuts and removal of debris, 25kg was gotten and was used to carry out the research.

Fig. 2.1 Some Dikanut kernels placed in a plate

Seed Conditioning/Rewetting:

The initial moisture content of the Dika nuts was determined by oven method as described by ASAE (2003) and was found to be 7.02% using Eqn. 1:

$$MC = [(w_1 - w_2)/w_2] \times 100\% \quad \ldots 1$$

Where w_1= Initial weight of sample;

w_2= Final weight of sample;

MC = moisture content

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During moisture conditioning of the nuts, a batch of 4.5kg (batch 1) was kept at the initial moisture content of 7.02% without any further addition of moisture. The rest of the seeds were then divided into 4 parts/batches of 4.5kg each and were conditioned to obtain four different moisture content levels between 10.2% to 15.2% dry basis (hence giving a total of 5 batches). This was done by adding different calculated amounts of water to each batch of the Dikanut (Irvin*gia wombolu*), using Eqn. 2 (Zareiforoush et al., 2009);

$$Q = A(b - a)/(100 - b) \qquad \ldots 2$$

Where Q = mass of water to be added (g)

A = Initial mass of sample (g)

a = Initial moisture content of sample (%dry Basis)

b = Final/desired moisture content (%dry basis)

They were mixed thoroughly and then sealed in cellophane bags.

The batches were kept in a refrigerator at 2^0C - 5^0C for about 5days to allow for even distribution of water throughout the individual seeds of each sample. Before each test was started, the sample was exposed for about 2 hours for equilibration to occur (ASAE Standards, 2003).

Physical Properties

The principal dimensions of the nuts were determined using a micro-meter screw guage with an accuracy of 0.02mm.

Similarly, the arithmetic mean diameter (F_1), geometric mean diameter(F_2), square mean diameter(F_3), equivalent diameter(D_e) were determined respectively using the formulae by and Asoegwu et al., (2006) given in Eqns. 3-7;

$$F_1 = (L_1 + L_2 + L_3)/3 \qquad \ldots 3$$

$$F_2 = (L_1 \times L_2 \times L_3)^{1/3} \qquad \ldots 4$$

$$F_3 = [(L_1 L_2 + L_2 L_3 + L_3 L_1)/3]^{1/2} \qquad \ldots 5$$

$$D_e = (F_1 + F_2 + F_3)/3 \qquad \ldots 6$$

Where L_1, L_2 and L_3 = major, intermediate and minor diameters (triaxial dimensions)

The kernel aspect ratio was determined by using Eqn. 7 by Seifi and Alimardani (2010);

$$R_{as} = L_2/L_1 \qquad \ldots 7$$

Where R_{as} = Aspect Ratio;

Similarly, kernel surface area (A_s) and kernel volume (V) was calculated using the following relationships shown in Eqns. 8-10 (Subukola and Onwuka, 2011).

$$A_s = \pi B L_1^2/(2L_1 - B) \qquad \ldots 8$$

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$$V = \pi B^2 L_1^2/6(2L_1 - 3) \qquad ...9$$

Where $B = (L_2L_3)^{0.5}$ …10

And π = Mathematical constant

The bulk density which is the ratio of the mass of the kernels to its total volume was determined by filling up a 1000mL beaker with samples, striking off the top level without kernel being compacted in any way, weighing the set up and subtracting the weight of the beaker. Eqn. 11 was used (Amin et al., 2004; Subukola and Onwuka, 2011) to determine bulk density;

$$\varrho_{bulk} = \text{bulk kernel mass}/\ 1000\text{mL} \qquad …11$$

The true density was determined using toluene displacement method. Toluene was used in place of water because it is absorbed by the kernels to a lesser extent and also has a low surface tension with low dissolution power too (Aydin, 2002). 500mL of toluene was put in 1000mL graduated measuring cylinder. Kernels from each batch were first weighed using an electronic weighing balance and then immersed in toluene in six replicates. The amount of displacement was recorded as the volume. Hence true density (ϱ_{true}) was obtained using Eqn. (12);

$$\varrho_{true} = W / (V_2 - V_1) \qquad …12$$

where V_2 = final volume, V_1 = initial volume, W = weight of kernel

Porosity (ε) was determined as a function of the volume fraction ($f_v = \varrho_{bulk} / \varrho_{true}$). The porosity expressed in percentage was calculated using Eqn. 13 (Asoegwu et al., 2006; Joshi et al., 1993; Deshpande et al., 1993; Suthar and Das, 1996; Nelson, 2002);

$$\varepsilon = (1 - f_v) \times 100\% \qquad …13$$

Sphericity (ϕ)was calculated using Eqn. 14 by Asoegwu et al., (2006) and Gupta and Das (1997)

$$\Phi = F_2/L_1 \qquad …14$$

Where F_2 = geometric mean diameter

The angle of repose (θ_r) was determined at different moisture contents using square box method. In this method, a specially constructed square box with removable front cover was used. The box was filled with the kernels from each batch; the front cover was then quickly removed, allowing the kernels to flow to its natural angle. The height (H) of the kernels in the box as well as the length of spread (L) was measured and Eqn. 15 (Kingly et al., 2006) was used to determine the angle of repose for the different moisture contents:

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Fig 2.2 Measurement of angle of repose using square box method

$\Theta_r = \tan^{-1} (H/L)$ …15

Where H = maximum height of kernels(mm); L = spread length(mm);

Θ_r = angle of repose

The static coefficient of friction of the various sample batches was determined against four (4) different structural materials, namely; mild steel, aluminium, plywood and plastic. A carton was filled up to the brim with samples from each batch at a time and placed inverted on the structural surface lying on an adjustable tilting table. The carton was raised slightly so as to prevent the edges from touching the surface of the structural material. One edge of the entire set up was raised gradually using the tilt table screw device until the inverted carton of samples started to slide down and the angle of tilt (α) was read off using a protractor. Eqn. 16 was then used to determine the values of the static coefficient of friction (μ) on these structural surfaces at different moisture content levels (Singh and Goswami, 1996; Isik, 2007)

$\mu = \tan \alpha$ …16

All resultant values generated in this research were statistically analysed using Microsoft office excel 2010. Regression models of the effect of moisture on all the properties were developed and discussed.

RESULT AND DISCUSSION

REWETTING

The following amount of water were added to the African locust beans after being calculated with respect to mass of samples contained in each batch and its initial and desired moisture content level.

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Table 3.1 Rewetting parameters for batches of samples

Batch	A(kg)	Q (kg)	b (% db)
1	4.50	**Nil**	**7.02**
2	4.50	0.12	9.45
3	4.50	0.22	11.36
4	4.50	0.31	12.97
5	4.50	0.43	15.04

Physical Properties

Some of the physical properties of the kernels, grouped into five (5) batches of moisture content values given in Table 3.1 were respectively analysed.

Seed dimensions

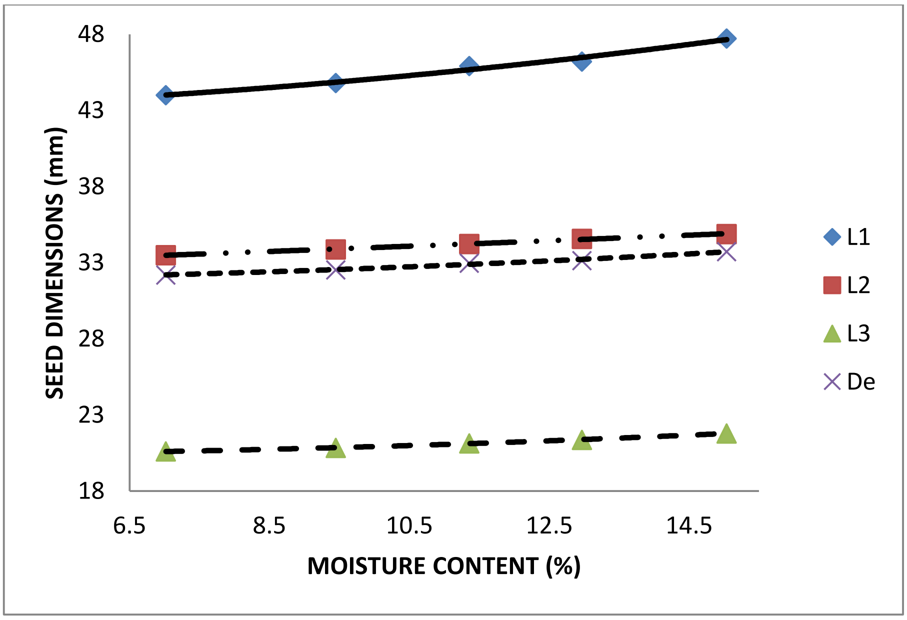

Fig. 3.1 Effect of moisture content on seed dimensions

The following regression models were developed to this effect and given in Eqns. 17-20;

$$L_1 = 0.019M^2 + 0.0285M + 42.859 \quad (R^2 = 0.9828) \quad \ldots 17$$

$$L_2 = 0.0014M^2 + 0.1468M + 32.39 \quad (R^2 = 0.9978) \quad \ldots 18$$

$$L_3 = 0.0078M^2 - 0.025M + 20.39 \quad (R^2 = 0.9996) \quad \ldots 19$$

$$De = 0.0081M^2 + 0.0092M + 31.735 \ (R^2 = 0.9896) \quad \ldots 20$$

Major, intermediate, minor and equivalent diameters were seen to have exhibited a polynomial increase as moisture content increases. This is due to the fact that the kernel dimensions

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increase when the kernel absorbs more moisture because more matter is then added to the kernel; hence there is an expansion in its dimensions.

Zeifouroush et al. (2009) reported a linear response too for paddy grain. Amin et al. (2004), Subukola and Onwuka (2011), Seifi and Alimardani (2010) and Tavakoli et al. (2009) all posited linear response of seed dimensions to moisture increase for lentil seeds, locust bean (*Parkia fillicoidea*), corn and barley grain respectively. However, it has been found that a polynomial model had a higher coefficient of determination (R^2) and thus is the model recommended in this work for the dimensions of Dikanut (*Irvingia wombolu*).

Seed volume and surface area

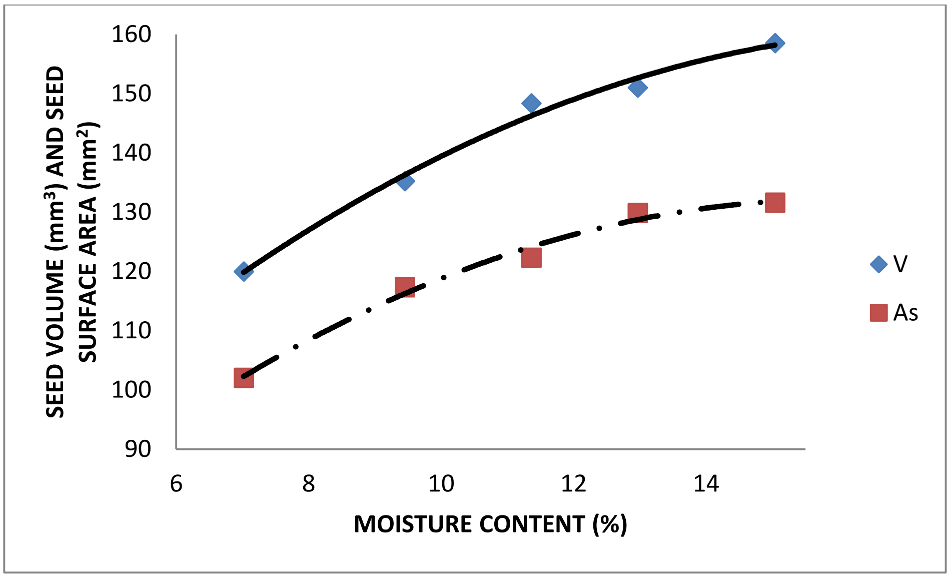

Fig. 3.2 Effect of moisture content on seed volume and surface area

The following regression models (Eqns. 21and 22) were developed to these effects;

$$V = -0.354M^2 + 12.59M + 48.908 \quad (R^2 = 0.9908) \quad ...21$$

$$A_S = -0.3681M^2 + 11.805M + 37.542 \quad (R^2 = 0.951) \quad ...22$$

This is does not agree with the suggestions of some researchers like Seifi and Alarmadani (2010) who suggested a linear model for seed volume and seed surface area as moisture content of corn increased. Zareiforoush et al. (2009) posited a linear model for these properties too for paddy rice.

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Density

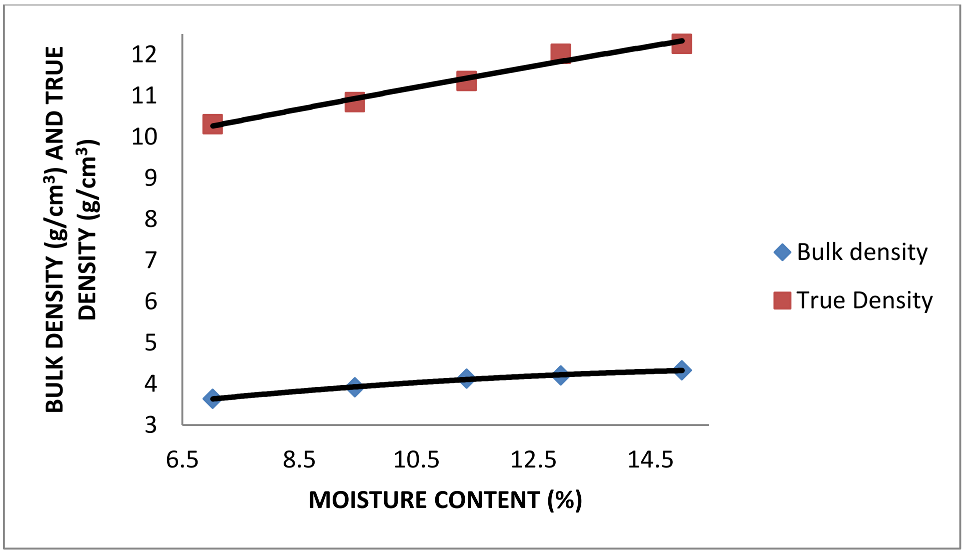

Fig. 3.3 Effect of moisture content on densities

Eqns. 23 and 24 are regression models generated to this effect

$$\varrho_b = -0.0062M^2 + 0.222M + 2.384 \quad (R^2 = 0.9974) \qquad \ldots 23$$

$$\varrho_t = -0.0029M^2 + 0.3223M + 8.1491 \quad (R^2 = 0.9796) \qquad \ldots 24$$

From Fig. 3.3, densities (bulk and true) showed a polynomial increase though a linear behaviour was suggested by Amin et al. (2004) for both the bulk and true densities of lentil seeds with respect to moisture content variance. Asoiro and Ani (2011) suggested an average safe storage density of yam bean to bean to be 1.02g/cm^3 and 1.00g/cm^3 respectively for true and bulk densities. Nimkar and Chattopadhyay (2001) posited a linear model for the density of green gram which had the range of 807g/cm^3 to 708g/cm^3 (bulk density) and 1363g/cm^3 to1292g/cm^3 (true density).

Aspect ratio, Sphericity and Porosity

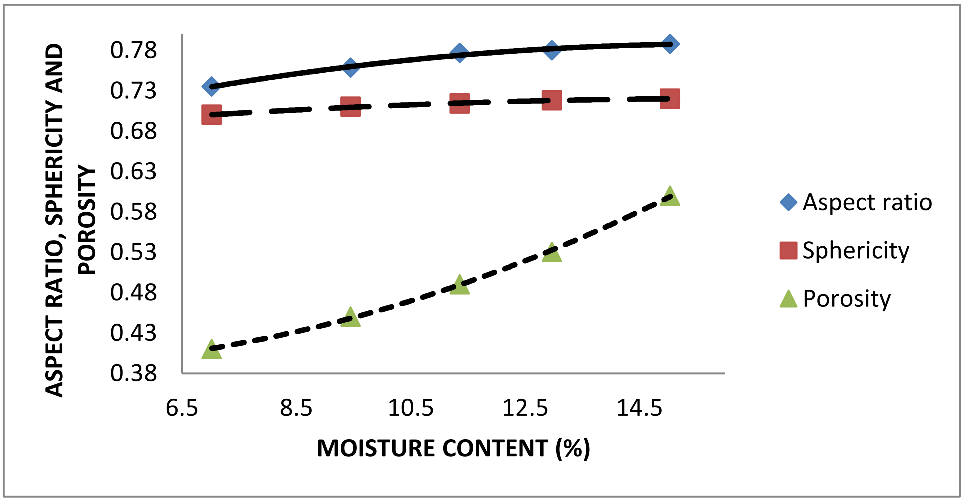

Fig. 3.4 Effect of moisture content on aspect ratio, sphericity and porosity

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The following regression models (Eqns. 25-27) were developed to this effect;

$$A_SR_a = -0.0007M^2 - 0.0212M + 0.6185 \ (R^2 = 0.9914) \qquad ...25$$

$$\Phi = -0.0002M^2 + 0.0077M + 0.6577 \ (R^2 = 0.9964) \qquad ...26$$

$$\varepsilon = 0.0014M^2 - 0.0084M + 0.3984 \quad (R^2 = 0.9994) \qquad ...27$$

Similarly, Fig. 3.4 shows a polynomial increase for all the dimensionless properties studied in this research. Seifi and Alimardani(2010) suggested a linear response for the aspect ratio and sphericity of corn. Subukola and Onwuka (2011) and Zareiforoush et al. (2009) suggested a linear behaviour too for the sphericity of *Parkia fillicoidea* specie of locust bean and paddy grain respectively. Nimkar and Chattopadhyay (2001) suggested a linear increasing response of porosity for green gram. Kingly, et al. (2006), Subukola and Onwuka (2011) and Tavakoli et al. (2009) suggested a decrease in porosity of pomegranate seeds, *Parkia fillicoidea* specie of locust bean and barley grains respectively with increasing moisture content.

Frictional Properties

Some frictional properties of Dikanut which were studied as a function of moisture content gave the following results which define seed flowability as a function of moisture content;

Static coefficient of friction

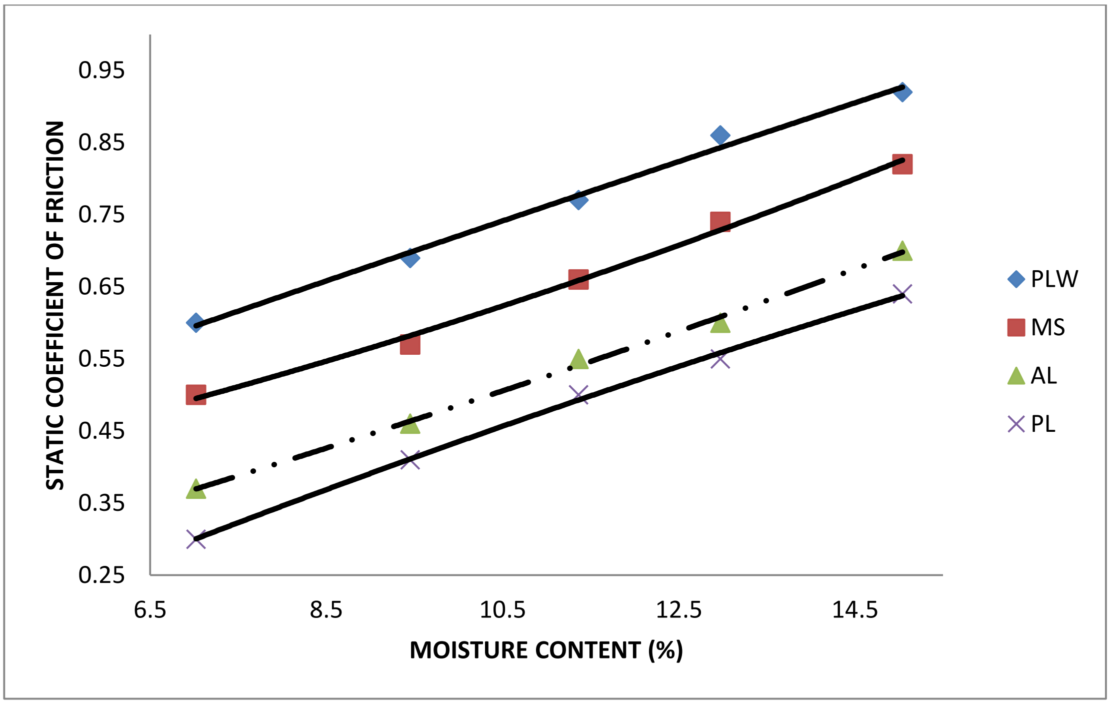

Fig. 3.5 Effect of moisture content on static coefficient of friction

The static coefficients of friction of friction on the five different surfaces and at five different moisture content levels are shown in Fig. 3.5 above. It can be observed that the static coefficient of friction for all the structural surfaces tested in the experiment had a polynomial increase as moisture content increases, with plywood having the highest coefficient followed by mild steel and lastly plastic. These are given in Eqns. 28 - 31:

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$$\mu_{PLW} = -0.0001M^2 + 0.0436M + 0.2949 \quad (R^2 = 0.993) \qquad \ldots 28$$

$$\mu_{MS} = 0.001M^2 + 0.0199M + 0.308 \quad (R^2 = 0.9948) \qquad \ldots 29$$

$$\mu_{AL} = 0.0004M^2 + 0.0318M + 0.1259 \quad (R^2 = 0.9974) \qquad \ldots 30$$

$$\mu_{PL} = -0.0006M^2 + 0.0558M - 0.0603 \quad (R^2 = 0.9981) \qquad \ldots 31$$

This is due to the fact that the kernels become stickier as moisture content increases, leading to more resistance to relative motion between nuts and the surface. This increase in resistance therefore leads to an increase in the coefficient of static friction. It was also observed that the coefficient of static friction also varied with surfaces, this was as a result of the dependency of frictional properties and mechanical behaviour of a material on the microstructure of the material. Structural material grains shape and their crystallographic orientation are two features of microstructure that affect friction on this material. Due to the difference in crystallographic orientation of the grains which creates a difference in the surface texture, the material grains of the two surfaces prevent sliding freely on surface. The rougher the grains, the more the surfaces interlock, resulting in more resistance to relative motion between them which equally leads to increase in the coefficient of static friction. The material grains of plywood are rougher than those of mild steel and aluminium, hence, the reason for the high coefficient of static friction with plywood. Therefore, the power demand of processing machines involving friction increases with increase in moisture content and also with increase in coefficient of static friction. This implies that in plywood constructed machines, higher power will be required than in similar machine constructed with aluminium.

Asoiro and Ani (2011) posited linear increase for average values of coefficient of static friction of African yam bean from aluminium to asbestos than plywood at a safe moisture content. Oje and Ugbor (1991) suggested a linear increase too for oil bean seeds using galvanized steel, plywood, stainless steel, aluminium and mild steel with a simultaneous increase in moisture content and equally posited that plywood gave highest values. Kingly et al. (2006) posited a linear increase too for pomegranate seeds for various structural surfaces with plywood giving the highest values.

Angle of repose

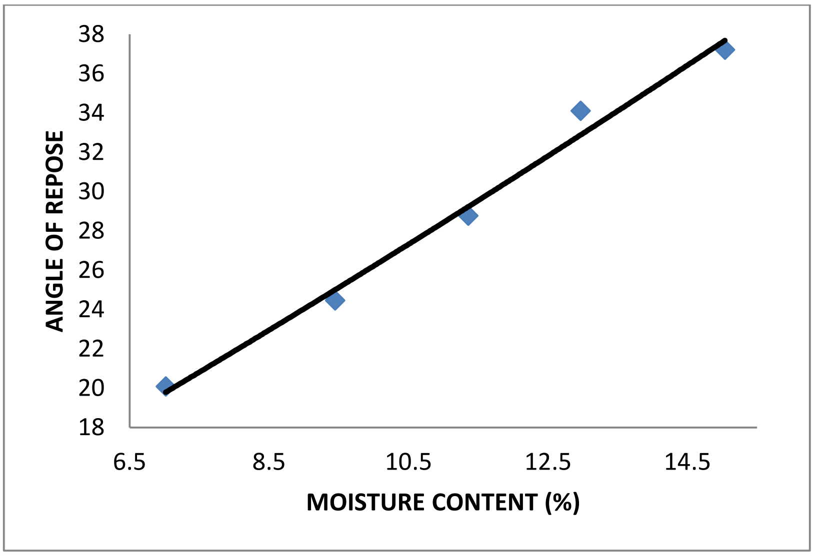

Fig 3.8 Effect of moisture content on angle of repose

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Fig 4.8 shows the angle repose at five different moisture contents and it was observed that the angle of repose had a polynomial variation with increase in moisture content. This is given in Eqn. 32:

$$\Theta_R = 0.0155M^2 + 1.8892M + 5.7693 \quad (R^2 = 0.988) \qquad \ldots 32$$

Reason being that, the higher the moisture content, the higher the cohesion between the seeds. In terms of flowability, the seeds are heavier and the inertia to move is increased. This increase in resistance to flow prevents seeds from sliding on each other, thereby increasing the angle of repose of the seeds. Nimkar and Chattopadhyay (2001) , Subukola and Onwuka (2011), Tavakoli et al. (2009) and Zareiforoush et al. (2009) all suggested a linear increase too for green gram seeds, *Parkia fillicoidea* specie of locust bean, barley grains and paddy grains respectively.

These regression models generated in this research can be used to predict mathematically these respective properties of Dikanut (*Irvingia wombolu*) within the moisture content range of 7.02 to 15.04% (dry basis).

CONCLUSIONS

1. The nut was found to be oblate spheroid in shape.
2. All properties studied were found to have a polynomial response to moisture content increase within the moisture content range studied (7.02 to 15.04% dry basis).
3. The average dimensions; major, intermediate and minor and equivalent diameters increased from 44.00 to 47.73mm, 33.50 to 34.89mm, 20.60 to 21.79mm and 32.20 to 33.73mm respectively as moisture content increased from 7.02 to 15.04% (dry basis).
4. The seed volume and the seed surface area of *Irvingia wombolu* increased from 120.01mm^3 to 158.56mm^3 and 102.04mm^2 to 131.64mm^2 within the range of moisture content tested.
5. Bulk density and true density increased from 3.64g/m^3 to 4.33g/m^3, and 10.31g/m^3 to 12.26g/m^3 respectively with increase in the moisture content range tested.
6. Aspect ratio and sphericity and porosity of *Irvingia wombolu* varied with increase in the tested moisture content range from 0.74 to 0.79; 0.70 to 0.72; 0.41 to 0.60 respectively.
7. Angle of repose increased from 20.10° to 37.20° while static coefficient of friction increased from 0.60 to 0.92 (plywood), 0.50 to 0.82 (mild steel), 0.37 to 0.70 (aluminum), 0.30 to 0.64 (plastic) as moisture content increased from 7.02 to 15.04% (dry basis).

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